A New Initial Conditions Generator for `MANGA`

1 Introduction

Numerical simulations have played a crucial role in understanding the hydrodynamics of gas, stars, disks, galaxies, and other astrophysical phenomenon. In astrophysics, two dominant methodologies have emerged to numerically solve the fluid equations: smooth particle hydrodynamics (SPH) and grid-based solvers.

SPH is based upon the Lagrangian view of the fluid equations where fluid quantities are determined from a finite sampling of nearby particles, i.e., fluid quantities like density and pressure are computed using a smoothing kernel over a number of neighbors. SPH conserves linear and angular momentum well, but this comes at the expense of comparatively poor resolution of shocks (Springel 2005). On the other hand, grid based methods have superior shock capturing abilities due to the use of Godonov schemes, but suffers from grid effects, which limit angular momentum conservation, and possibly lead to violations of Galilean invariance (Springel 2010). These numerical deficits could also introduce significant inaccuracies in simulations of TDEs.

Recently, a new class of numerical methods have emerge to solve the fluid equations. These new moving-mesh methods are a class of arbitrary Lagrangian-Eulerian (ALE) schemes that have been devised as an effort to capture the best characteristics of both Lagrangian and Eulerian approaches, combining superior conservation properties with superior shock capturing. In particular, Springel (2010) has developed a ALE scheme that has proven successful in computational astrophysics. Implemented into the code, AREPO, the scheme relies on a Voronoi tessellation to generate a well-defined and unique mesh for an arbitrary distribution of points on which finite volume methods are applied.

It has been argued that the use of ALE schemes is important to maintain the Galilean invariance of Eulerian schemes (Springel 2010). It has also been shown that these schemes are superior at capturing boundary layer instabilities such as Kelvin-Helmholtz instabilities compared to SPH and Eulerian grid schemes (Springel 2010, but also see Lecoanet et al. 2016). In any case they do seem ideal to model colliding galaxies or stars. In particular, AREPO has been used in a number of different problems including cosmological galaxy formation (Vogelsberger et al. 2014), and stellar mergers (Zhu et al. 2015; Ohlmann et al. 2016).

One such code that has been mainly developed at UWM is the moving-mesh code, `MANGA`. `MANGA` (Chang et al. 2017) solves the fluid equations using the scheme proposed by **?** and has been applied to dynamical stellar problems such as stellar mergers (Chang et al. 2017), common envelope evolution (Prust & Chang 2019), and TDEs (Spaulding & Chang 2021).

2 Proposed Project

A major aspect of numerical simulations is a means to specify initial conditions. The generation of initial conditions is none trivial and in the case of moving-mesh methods, initial conditions play an important role in the speed and accuracy of the resulting code. However, `MANGA` is based on an old SPH framework called `ChaNGa`, and much of the initial conditions is based on it. Namely, it generates initial conditions using an SPH framework.

This has the important advantage in that the same initial conditions can both be use to simulate the same problem using SPH and moving-mesh methods. In practice, however, initial conditions for SPH and moving-mesh simulations are different and should not be used inter-changably. However, this design decision that was made at the beginning still haunts the simulations carried out using `MANGA`. **The goal of this project is to develop a new initial conditions generator that is free from this limitation and promises to be more flexible for more generic simulations.**

The new initial conditions generator can be constructed entirely in Python. It would rely on the quirks of how restarts are handled in `MANGA` to create the appropriate initial conditions files that can be handled seamlessly. By doing so, we can separate how initial conditions are generated from the codebase of `MANGA`.

Two important skills will be required to complete this project. The first will be extensive knowledge of the python programming language and the second is some knowledge of Numpy so that vectors can be appropriately manipulated.

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